TECHNICAL REPORT

FUNCTIONAL DESCRIPTION OF THE ACTIVE ACOUSTICAL SENSOR RANGE PREDICTION MODEL (ACTIVE ASRAP)

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FOREWORD

The Integrated Command ASW Prediction System (ICAPS) was developed by the Naval Oceanographic Office (NAVOCEANO) to predict the impact of the ocean environment on anti-submarine warfare capabilities. One of the ICAPS predictive computer models is the Active Acoustic Sensor Range Prediction Program (ACTIVE ASRAP), which provides range predictions for two active sonobuoys. This report illustrates the functional and mathematical techniques used in ACTIVE ASRAP. It will be found useful by the ASW tactician for evaluating the program's capabilities and applications.

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Captain, USN
Commanding Officer

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The Integrated Command ASW Prediction System (ICAPS) is an on-scene computer system designed as an anti-submarine warfare aid consisting of environmental, acoustic, and tactical products. One tactical model in ICAPS is the Active Acoustic Sensor Range Prediction model (ACTIVE ASRAP) which gives 50% probability of detection ranges for the SSQ-47 and the SSQ-50 sonobuoys. This report consists of a detailed description of ACTIVE ASRAP. The description is in terms of explicit formulation of the mathematical techniques used.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) in the model so that the reader can examine the inherent assumptions and the applicability of the program for his use. The audience is the general anti-submarine warfare community within U.S. Naval Forces.

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I. Introduction

The Integrated Command ASW Prediction System (ICAPS) is an on-scene computer system designed as an anti-submarine warfare aid consisting of environmental, acoustic, and tactical products. It allows processing of current bathythermograph data which is merged with data from an extensive historical data base to produce a sound velocity profile. The profile is used to drive a propagation loss model; its output drives several tactical models. Alternately ICAPS contains two tactical models, SHARPS and ACTIVE ASRAP, which generate their own propagation loss curves. The purpose of this report is to explain the basic flow of the ACTIVE ASRAP program, and to exhibit in analytical form the equations used. Since the program was developed by Fleet Numerical Oceanography Center, rather than by NAVOCEANO, and no prior documentation existed on it, the material presented here was derived primarily from examination of computer code. The following represents an appraisal of the model's mathematical/acoustic techniques based on a construction from source code.

The model computes ranges at which probability of detection is 50% for the SSQ-47 and SSQ-50 sonobuoys. For the SSQ-50, calculations are made for each of four modes and for each of four frequencies. Calculations are made for one mode and six frequencies for the SSQ-47. For each buoy/mode combination, there are four subcases corresponding to the depths at which the target and receiver are located, namely, shallow/shallow, deep/shallow, shallow/deep, and deep/deep.

II. General Description of the Program

ACTIVE ASRAP operates on a rather simplistic application of the active sonar equation:

$$FOM=SL-RD-AN+TS+DI,$$

where FOM is the figure of merit;
SL is the source level;
RD is the recognition differential;
AN is the ambient noise level;
TS is the target strength;
and DI is the directivity index.

Ranges for each target/transducer depth pair are found by computing the figure of merit for the particular buoy/frequency/mode combination, computing the propagation loss curve, and finding the first range at which the FOM equals twice the propagation loss. In this way a 50% range is determined; however, note that only direct-path ranges are found--this is valid due to the sonobuoys' roles as localization, rather than detection, tools.

At the outset, values of SL, RD, TS, and DI are retrieved from tables; optionally, the user may input RD and TS. Next the operator-input wave height to be used is read from the terminal, and the sound velocity profile is read from an auxiliary file created by a prior run of one of several ICAPS programs. Here we denote sound speed by C and depth by Z. The profile is an array $\{(Zi, Ci): 1 \leq i \leq NOPTS\}$, where NOPTS represents the number of points value from the profile generator model.

Sonic layer depth (SLD) is computed next. ACTIVE ASRAP traces the profile from surface to bottom and sets SLD as the first depth where the profile gradient ($\Delta C/\Delta Z$) begins to turn negative.

There are six and four frequencies associated with the SSQ-47 and SSQ-50 buoys, respectively. For each frequency f, an ambient noise value is computed by

$$AN=13.5634704 \cdot h^{(1/5)} -5 -17(\log f),$$

Where h represents the wave height as represented by the Wenz curves.

For each buoy, stored values for target and transducer depths are used except for the deep target depth. For that case, the target depth is 30 $\sqrt{ZL}$ or 100 feet if no layer exists (with a maximum value of 600 feet). This represents an accepted operational depth for a submarine to avoid detection by an active sonar.

Next propagation loss curves are computed for each frequency; this calculation will be discussed below in Section III.

Once the transmission loss calculations for the target/transducer depth pair have been completed, a final calculation is performed for each frequency/mode pair. As described above, an FOM is computed; the propagation loss curve is searched until the first range is found such that twice its propagation loss value is greater than or equal to the FOM. An interpolation gives the exact range where twice the transmission loss equals the FOM.

When all ranges have been computed, a tabular output of the ranges in kiloyards completes the execution.

III. Description of Propagation Loss Calculations

By assuming the reciprocity principle is valid for active sonar, target and transducer can be interchanged. Here it is assumed that target depth is less than or equal to transducer depth. These depths are inserted into the profile along with interpolated sound speed values to give a complete profile, $\{(Zi, Ci): 1 \leq i \leq NL\}$. (NL represents the NOPTS value adjusted for the addition of the target and transducer depths.) The gradient of the profile is computed by

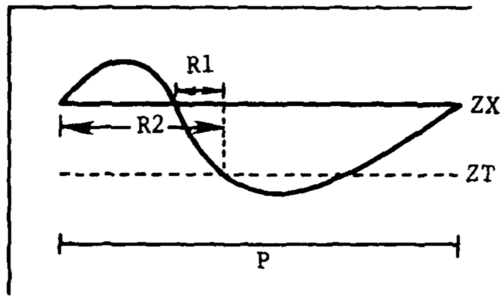
$$g_i = \frac{C_{i+1} - C_i}{Z_{i+1} - Z_i}, \quad 1 \leq i \leq NL - 1.$$

Let ZX and ZT denote the target and transducer depths, respectively; ZL will denote the sonic layer depth, and CL will denote the sound speed at that depth.

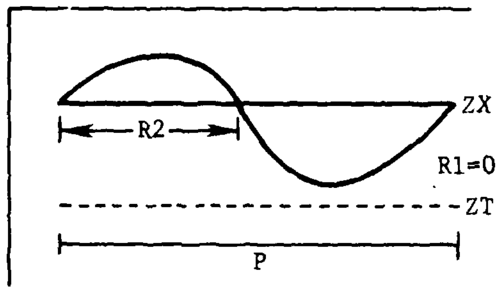
The angle at which a sound ray traced from the source will have the longest period is given by $\theta = \cos^{-1}$ (CX/ CL). Using this fact, various computations are made to determine the following parameters:

R1 = range of ray to first arrival of the ray
R2 = range of ray to second arrival of the ray
P = period of ray. (See figure 1.)

Case 1: Ray crosses transducer depth.



Case 2: Ray vertexes before reaching transducer depth



Case 3: Target and Transducer at same depth.

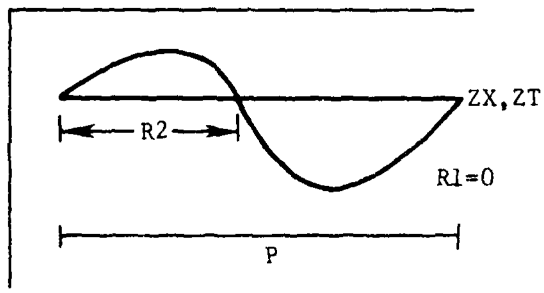


Figure 1. Arrivals of a ray

The computations utilize the fact that in a layer where sound speed is a linear function of depth, ray paths are arcs of circles. Consider such a layer where the ray is traveling upward:

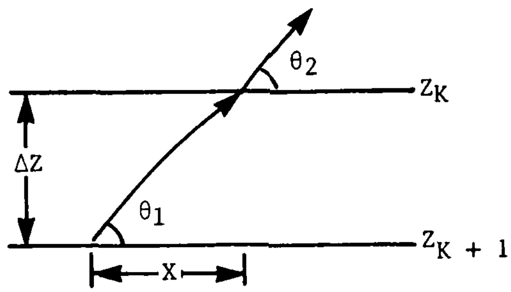


Figure 2. Ray path in a layer

If the ray does not vertex in the layer, X (range) is given by

$$X = \Delta Z \frac{\text{Cos } \theta_2 + \text{Cos } \theta_1}{\text{Sin } \theta_2 + \text{Sin } \theta_1}$$

If the ray does vertex in the layer ($\theta_2 = 0$), then X is given by

$$X = \left| \frac{CL \cdot \text{Sin } \theta_1}{g_k} \right|$$

Analogous expressions are used for the case where the ray is traveling downward. The values R1, R2 and P are obtained by taking the appropriate sums of the individual layer range increments.

For each frequency f, several parameters are computed:

$$\Gamma = \begin{cases} 1.59 \sqrt{hf} & \text{if } hf > 4.2691 \\ 10 \log (1 + ((hf)^4 / 293.7658)) & \text{if } hf \leq 4.2691 \end{cases}$$ (Surface reflection loss coefficient)

$$\alpha = \left(\frac{.1}{1 + f^2} + \frac{40}{4100 + f^2} \right) f^2$$ (Thorp's absorption coefficient, ref. 2)

A low-frequency cutoff term is calculated based on an approximation to the normal-mode surface-duct model of Pederson and Gordon (ref. 1). Use is made of a stored curve of imaginary eigenvalues for the first mode vs. a ducting parameter computed by

$$M = 1000 \, (8\pi^2 f^2 \gamma_0)^{1/3} \, (ZL/CL),$$

where γ_0 is the gradient of the duct, computed as though the profile were linear to the sonic layer depth. From this value, a corresponding value for Im (MX), the imaginary eigenvalue corresponding to M, is found by interpolation on the stored curve.

Finally, the cutoff term is computed by

$$\tau = \begin{cases} (3.816 \times 10^5)\ (f \cdot \gamma_0^2)^{1/3}\ (\mathrm{Im}(Mx)/(CL)) \\ \qquad\text{or} \\ (7.726 \times 10^5)\ (f \cdot \gamma_0^2)^{1/3}/CL \text{ if no duct exists.} \\ \quad\text{(In this case } \tau \text{ must be no less than 6.)} \end{cases}$$

The remainder of the computation proceeds as follows for each range point R:

I. If a surface duct exists ($\gamma_0 \geq 0$)

A. Target and receiver both in duct.

R1P=2·PERIOD - R2
NSB= (R+R2)/PERIOD (number of surface bounces)

B. Either target or transducer out of duct.

$R1P = R1 + (1/2)\sqrt{ZL}$

If $\gamma_0 = 0$, NSB = 0

If $\gamma_0 > 0$, $NSB = \dfrac{1500\ |\gamma_0|\ (R - R1P)}{\sqrt{(CL)^2 - (C_1)^2}}$

If NSB is less than 1, it is set to 0.

Then $HP = 20 \log R + \alpha R + (f/25)^{1/3} \cdot (25 - \sqrt{|ZX - ZL|} - \sqrt{|ZT - ZL|} + 5R) + 60$

(The third term is set to 0 if originally negative.)
If the target is out of the duct and $R \geq R1$, HP = 180.

$$NCO = \begin{cases} \tau \cdot R \text{ if NSB} > 0 \text{ (cutoff term)} \\ 0 \text{ otherwise} \end{cases}$$

If NSB < 1 or ZX > ZL, NSB = 1.

Finally, $H = TLOG(R,ZT) + \alpha R + (NSB-1)\cdot\Gamma + NCO + (f/25)^{1/3}\cdot GF(ZX,ZT) + (.4)\cdot CF\cdot KF(ZX,ZT)$.

Transmission loss, TL = minimum $\{H, HP, 180\}$.

II. If a surface duct does not exist:

$$H = \begin{cases} 20\cdot\log R1 + \alpha R + 60 \\ \qquad + 10\cdot\log(R/R1) + \tau(R-R1) \quad \text{if } R>R1 \\ 20\cdot\log R + \alpha R + 60 \quad \text{if } R \leq R1 \end{cases}$$

TL = minimum $\{H, 180\}$

III. Functions and Constants

$$CF = \begin{cases} (1/2)f^{1/3} & \text{if } f > 8 \\ 1 & \text{otherwise} \end{cases}$$

$$TLOG\ (R,Z) = \begin{cases} 10 \log (R \cdot R1P) + 60 & \text{if } R > R1P \text{ and } Z < ZL \\ 10 \log (R^2) + 60 & \text{otherwise} \end{cases}$$

$$G = \begin{cases} .1\left(10^{\left(2.3 \sqrt{\frac{ZT - ZX}{ZL}}\right)}\right) & \text{if } \sqrt{\frac{ZT - ZX}{ZL}} < 1 \\ 20 & \text{otherwise} \end{cases}$$

$$FACT = \begin{cases} \dfrac{R1P - R}{R1P - R1} & \text{if } R > R1 \\ R/R1 & \text{otherwise} \end{cases}$$

$$GF\ (ZX,\ ZT) = \begin{cases} 0 & \text{if } R \geq R1P \\ FACT \cdot G & \text{otherwise} \end{cases}$$

$$KF\ (ZX,\ ZT) = \begin{cases} 10^{\sqrt{ZX/ZL}} + 10^{\sqrt{ZT/ZL}} + 10^{\sqrt{ZT/ZL} - \sqrt{ZX/ZL}} & \text{if } R \geq R1P \\ \left(\dfrac{R - R1}{R1P - R1}\right)\left(10^{\sqrt{ZX/ZL}} + 10^{\sqrt{ZT/ZL}} + 10^{\sqrt{ZT/ZL} - \sqrt{ZX/ZL}}\right) & \text{if } R < R1P \end{cases}$$

$KF = 0$ if $R \leq R1$

CONCLUSION

ACTIVE ASRAP represents the Navy's standard tactical tool for evaluating detection ranges for the SSQ-47 and the SSQ-50 sonobuoys. To relate the capabilities and limitations of ACTIVE ASRAP to an operational scenario, an understanding of the mechanics of the model could prove useful to the ASW tactician. This report should provide assistance in obtaining such an understanding.

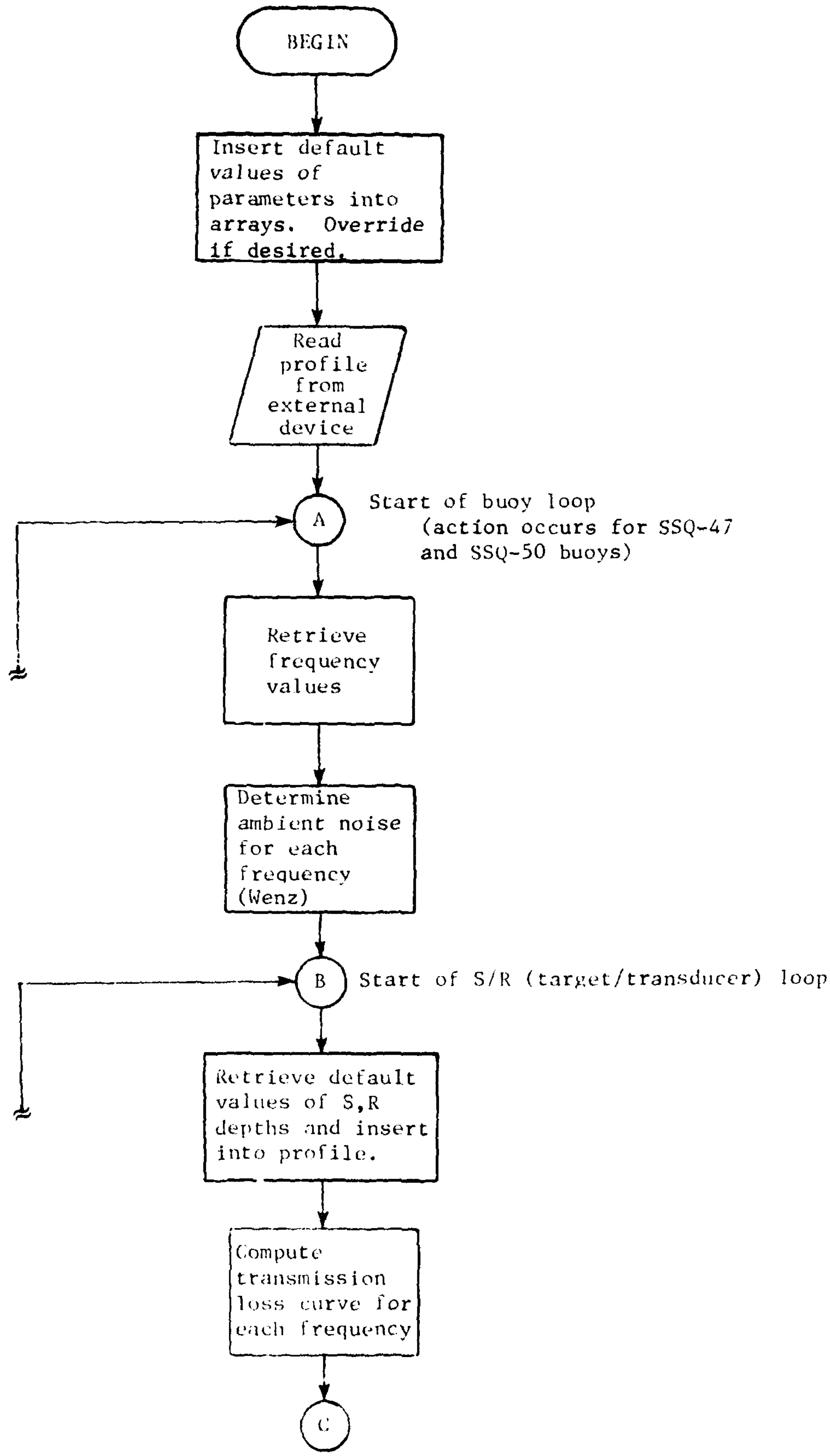
References

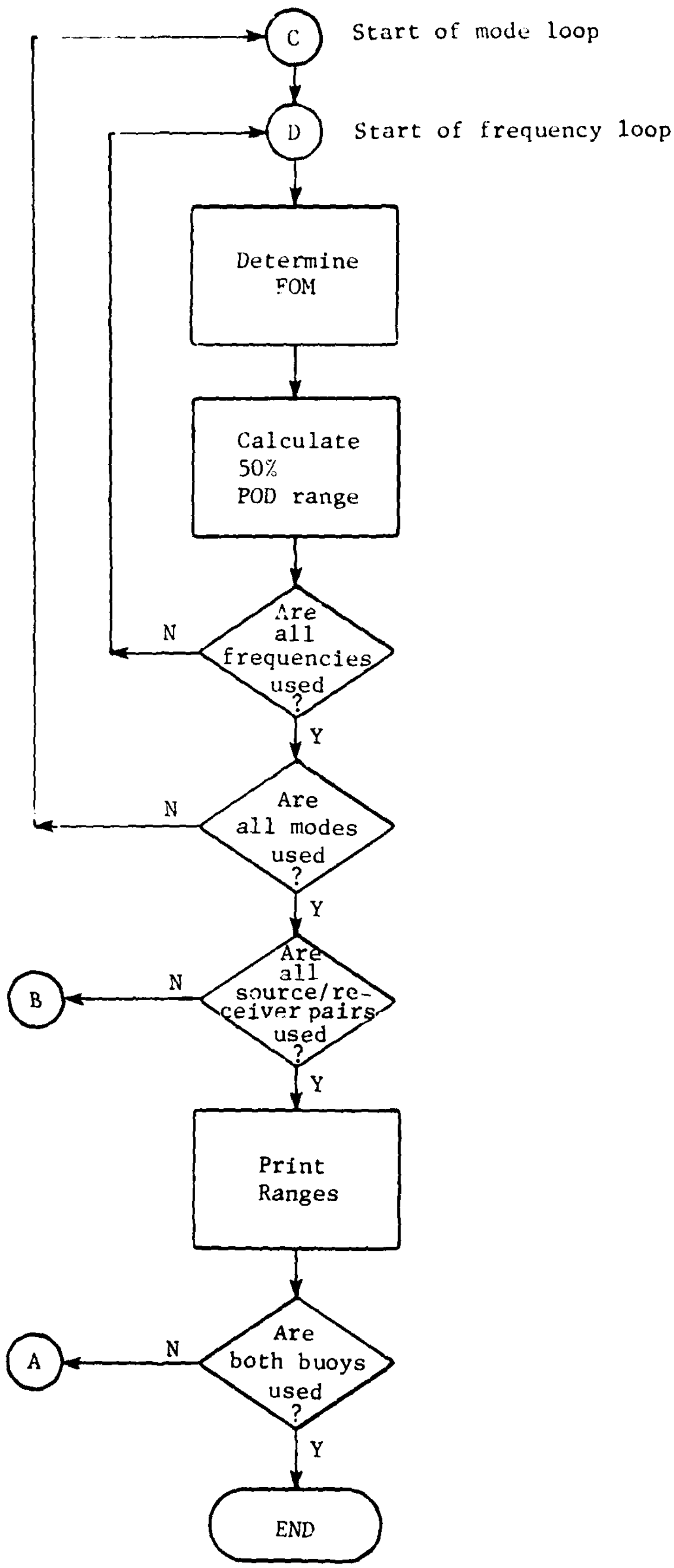
1. Navy Interim Surface Ship Model (NISSM) II, NUC Technical Publication 372, Naval Underwater Systems Center and Naval Undersea Center. 1973.

2. Principles of Underwater Sound, Urick, McGraw-Hill. 1975.

APPENDIX A

FLOW CHART FOR ACTIVE ASRAP


BEGIN
Insert default values of parameters into arrays. Override if desired.
Read profile from external device
A
Start of buoy loop (action occurs for SSQ-47 and SSQ-50 buoys)
Retrieve frequency values
Determine ambient noise for each frequency (Wenz)
B
Start of S/R (target/transducer) loop
Retrieve default values of S,R depths and insert into profile.
Compute transmission loss curve for each frequency
C


C
Start of mode loop
D
Start of frequency loop
Determine FOM
Calculate 50% POD range
Are all frequencies used ?
N
Y
Are all modes used ?
N
Y
Are all source/receiver pairs used ?
B
N
Y
Print Ranges
Are both buoys used ?
A
N
Y
END